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Estimation of the configurational parameters of a particle field requires accurate quantification of the location and orientation of each particle in a test volutme at one point in time. In-line holography is a useful technique, but previous reconstruction apprcaches fail for high density. Here the feasibility of highdensity in-line holography is studied in the context of a new superresolving digital reconstruction technique.

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ORIENTATION AND PAIR CORRELATION AT HIGH DENSITY BY SUPERRESOLUTION HOLOGRAPHY

FINAL REPORT

PETER D. SCOTT, PH.D.

JUNE 1 1992

U.S. ARMY RESEARCH OFFICE

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FOREWARD

This Final Report summarizes the principal results of research activities undertaken under Army Research Office Grant / Contract Number DAAL03-91-G-0144, award period 20 May 1991 - 19 November 1991, under the auspices of the Research Foundation of the State of New York. The referenced award, while covering a duration of six calendar months, had a single significant budget item: support of one month of the Principal Investigator's time during the Summer of 1991.

As detailed in the proposal 28359-GS directed to Dr. Walter Flood of the Geosciences Division, this modest duration and manpower committment was directed toward determining the feasibility of extending the Principal Investigator's research group's previous results in digital holography into new particle field regimes by the prototyping of superresolution algorithms designed for in-line holography. The previous results upon which this feasibility study is based were partially supported by the earlier Army Research Office grant DAA-L03-89-K-0134, final report date 15 December 1990.

STATEMENT OF THE PROBLEM STUDIED

Among the many techniques which have been proposed for studying the dynamics of ensembles of small particles, one of the few practical methods which is capable of gathering information on the instantaneous three dimensional configurations of each discrete particle is in-line far field holography [1]. A major difficulty in the use of this method is the limitation of accuracy inherent in the reconstruction process. Accurate quantitative decoding of the information encoded in in-line holograms, at best difficult optically, may be achieved by analog-to-digital conversion and sampling of the hologram followed by digitial reconstruction. Using standard reconstrcution techniques, the resulting image bandwidth is limited by the size of the hologram. In addition, the phase ambiguity inherent in magnitude-only hologram recording yields, along with the desired object reconstruction, an out-of-focus conjugate artifact called the twin image. Both limited bandwidth and twin image restrict the available resolution well below the theoretical diffraction limit.

This difficulty is particularly acute in the case of high particle field densities. In the opposite bounding case of extemely low densities associated with the well-stirred approximation, the twin images generated by neighboring particles have disjoint regions of significant support, and thus do not interfere optically on the recorded hologram. Thus the twin image of one particle does not contaminate the reconstruction of another. As density increases, since the region of significant suport of each particle extents many times farther than the real image of the particle, images on the hologram plane begin to encroach upon one another. At high density it becomes impossible to resolve individual particles using conventional optical technique, or even using the more accurate digital techniques developed previously in the Principal Investigator's laboratory [2]-[7], with accuracy commensurate with the quantitative high density configurational studies whose feasibility is the subject of this investigation.

Thus the present effort was focused on prototyping of digital hologrammetry technique permitting the enhanced suppression of twin image artifact in the high density regime where both optical technique and previous algorithms fail. Algorithms which iteratively combine phase retrieval and spectral continuation are sensitive to the constraints imposed on the physical extents of the objects (particles) being imaged. To maximize the power of this class of digital methods, an adaptive constraint algorithm was designed and tested. Effective use of adaptive constraints greatly accelerates convergence of the algorithm compared to fixed constraints. The constraint selection rule has an important error-correction property in which overconstraint is automatically iteratively corrected and the constrint set boundaries stably relax toward the actual object boundaries.

The adaptive constraint algorithm employs a convolution - deconvolution iteration combined with interior phase retrieval (since the missing phase information is necessary for successful spectral continuation). With standard constraint specifications, considerable computational time is needed due to the slow convergence of Gerchberg-Saxon like phase retrieval algorithms. By adaptive selection of the constraints in the object domain, convergence is accelerated without instability.

In the following sections, the results of this feasibility study are summarized and references and publications cited.

SUMMARY OF THE MOST IMPORTANT RESULTS

The purpose of this study was to investigate the feasibility of studying high density particle fields via in-line holography. Toward this end an algorithm for digital decoding of dense in-line holograms, designated as the Adaptive Constraint Algorithm (ACT) was developed and tested. Though not without its limitations, this algorithm succeeds in extending the quantitative usefulness of in-line holography to the desired regime. Moreover, by careful selection of the parameters of the algorithm the computational costs associated with the resolution enhancement are small.

For a full derivation and description of ACT, the reader is directed to references [7] and [8]. We conclude this section with two examples illustrative of the relative performance of ACT compared to previous algorithms in the case of closely juxaposed particles. Figure 1 is a 1-D example, showing (a) the pulse-type object, (b) its in-line hologram, (c) the portion of the hologram used for reconstruction, (d) its convention reconstruction, (e) its reconstruction after 100 ACT iterations, (f) its reconstruction after 1000 iterations. Figure 2 is a 2-D example, with (a) the three particles, (b) the in-line hologram, (c) the portion used for reconstruction, (d) the conventional reconstruction, (e) its reconstruction after 20 ACT interations, (f) after 500 ACT iterations.

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Hua, L. "Digital image processing for particle in-line holography: resolution enhancement and dynamic studies," Ph.D. disseration, SUNY at Buffalo Dept. of Elec. and Comp. Eng., 1991.

Hua, L.F., Xie, G., Shaw, D.T. and Scott, P.D. "Resolution enhancement in digital in-line holography," Proc. SPIE vol. 1635, pp. 142-151, 1990.

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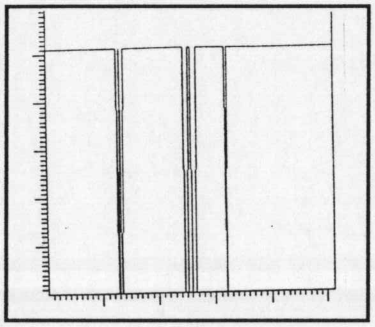
FIGURES (SEE TEXT FOR LEGENDS)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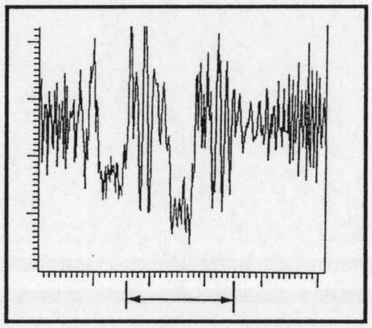
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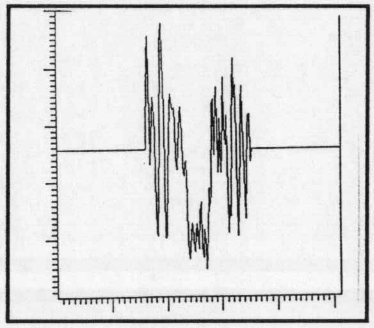
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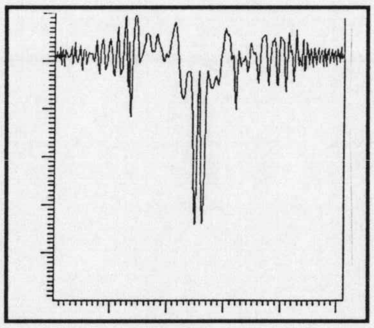
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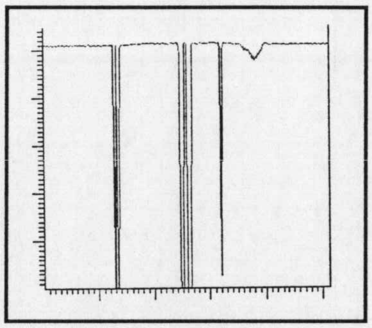
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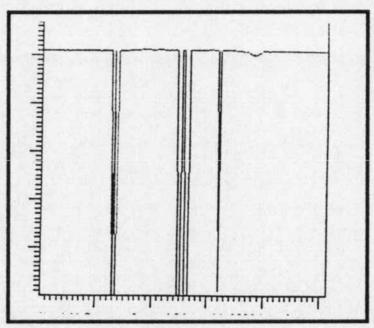
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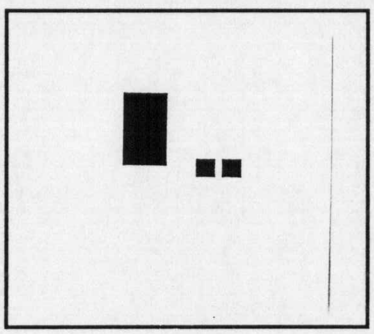
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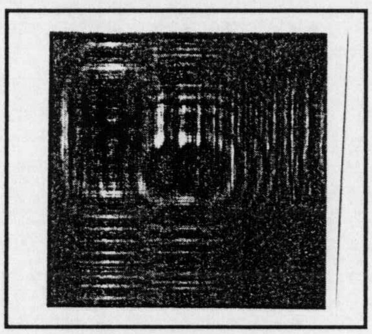
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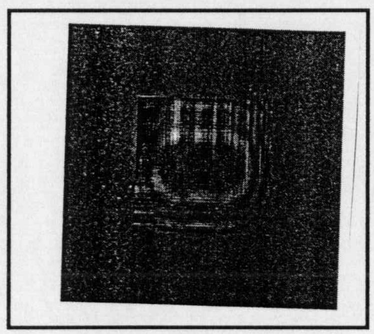
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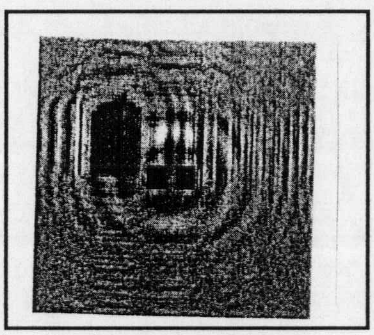
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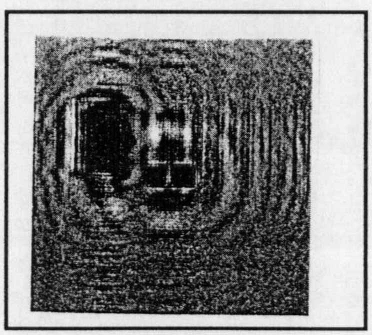
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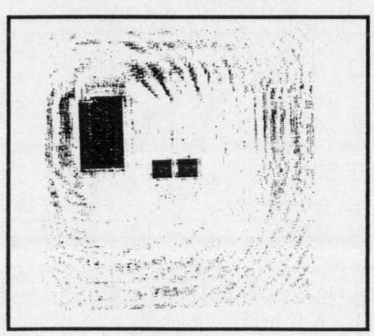
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